Patent Application of

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For

Gravity Balance Frame

Background - Field of Invention

This invention relates to the building design to resist seismic or wind loads.

Background - Description of Prior Art

Currently, the techniques of seismic resistant design for buildings can be divided into two general categories, conventional and alternate methods. The conventional method designs structural systems to absorb seismic energy or resist lateral load generated by seismic motions. The structural systems include moment frame, braced frame and shear wall. All these systems utilize the structural components alone to resist lateral load, and are therefore costly. The alternate method reduces the seismic input energy or load through installation of certain unconventional devices, such as base isolators or dampers. All these devices are complex, esoteric and incur substantial additional cost. In addition, both methods design a building for a predetermined level of seismic force. Once the seismic level exceeds the predetermined level, the safety margin decreases drastically. This occurs frequently due to the unpredictable nature of seismic events. In summary, the current seismic design methods for buildings have the following disadvantages:

(a) The conventional method utilizes the structural components alone to absorb seismic energy, and therefore the construction cost is high.

(b) The alternate method utilizes unconventional devices, and similarly the construction cost is high.

(c) Once the seismic level exceeds the predetermined design level, the safety margin will be decreased drastically.

There is one conventional braced frame design with v-shaped braces located at the centers of beams, and the configuration is geometrically similar to the present invention. However, the braces are designed to resist both tension and compression forces. This system is considered only an average seismic resistant design due to the lack of ductility. There is another tension-only braced frame with diagonal x-bracing. The system uses the strain energy of the bracing to absorb the seismic energy, and again is considered only an average design also due to lack of ductility. One alternate design system called a friction pendulum system, which uses low friction bearings to allow the structure to slide, and utilizes the structural weight to return the structure to the original position. However, the friction has to be low for the system to be efficient, and maintenance may be a problem. In addition, the system is not effective for wind load.

Objects and Advantages

An innovative concept has lead to a breakthrough in seismic design by including the gravity load to resist seismic loading. This is accomplished with the simple construction details of using v-shaped tension-only braces at heavily loaded girders. The objects and advantages of the present invention are:

(a) It reduces the cost of building construction due to inclusion of gravity load to resist the seismic loads, or in other words, it utilizes gravity potential energy to absorb the seismic energy, in addition to the conventional strain energy provided by the structural components.

(b) Both the material and the construction procedures are conventional, and therefore it is inexpensive to construct. Since it is simple to install, the system may be used for both new construction and retrofitting of buildings.

(c) Due to the utilization of gravity potential energy, the design provides a non-collapse system. The safety margin will not be decreased even if the seismic level exceeds the original design level.

(d) Due to the installation of braces at centers of heavily loaded girders, the lateral stiffness of the structure is increased substantially, especially for flexible moment frame buildings. This will reduce the deformation of buildings during moderate seismic events, and therefore minimize nonstructural damage.

(e) The system can be used for buildings constructed of any material, such as steel or reinforced concrete, as along as there are heavily loaded girders upon which the tension-only braces can be installed, and thus gravity potential energy can be utilized.

(f) Due to the installation of braces at the centers of girders, alternate rows of columns can be omitted on first floors. This will further reduce construction costs.

(g) Due to the absence of alternate rows of columns on the first floor, more available floor space will be provided. This is very appealing both functionally and architecturally.

(h) Although the concept is developed primarily for seismic resistant design, it can be used to resist wind load with the same efficiency.

Conclusion and Ramification

By installing v-shaped tension-only braces at centers of heavily loaded girders in buildings, the present invention provides for highly reliable seismic resistant structures. It reduces nonstructural damage during moderate seismic events, provides high safety margin during severe seismic events even if they are larger than the design level, and reduces construction cost. It can be used for steel or reinforced concrete structures, and is especially effective for flexible moment frame buildings. Due to its simple installation, the system may be used for new construction or retrofitting of buildings.

Although the design concept is developed primarily for seismic resistant design of buildings, it can be used to resist wind load with the same efficiency. The concept of utilizing gravity potential energy can also be used for other structures such as bridges.

Drawing Figures

In the drawings, closely related figures have the same number but different alphabetical suffixes.

Fig 1 shows a building structure with a Gravity Balanced Frame.

Fig 2 shows a conventional prior art building structure without a Gravity Balanced Frame.

Fig 3 shows one possible type of connection that can be used between the tension-only bracing and the girder that serves as part of the frame of a building.

Fig 4a to 4c show conventionally constructed connections between a steel column and girder.

Fig 5a to 5b show the basic concept behind Gravity Balanced Frame in operation in a children's toy, and a basic physics experiment.

Fig 6a to 6d show an undeformed and deformed Gravity Balance Frame and their corresponding conceptual representations.

Fig 7a to 7d show an undeformed and deformed conventional prior art structure and their corresponding conceptual representations.

Fig 8a to 8c show a prior art building structure, a building with a Gravity Balance Frame and a load deflection curve for a prior art structure and a Gravity Balance Frame.

Description - Figs 1,2,3,4

A Gravity Balance Frame utilizes gravity load in addition to strain energy to balance lateral loads and create a non-collapse, stable system under extreme seismic motion or wind. Fig.1 shows a Gravity Balance Frame where the lower end of tension-only braces **1** are connected to a gravity-loaded girder **3** and a beam-column joints at the other ends, in a frame type building constructed of column **2** and girder **3**. In comparison to a conventional prior art structure of similar size, as shown in Fig 2, the Gravity Balance Frame in Fig 1 requires less columns, affords longer girders, and results in more economical and functional design.

Fig 3 shows a connection, a conventional pin-hole type, between tension-only brace **1** and gravity-loaded girder **3** that could be employed in the Gravity Balance Frame shown in Fig 1. The design depicted in Fig. 3 is only one possible type of connection that could be used to connect the tension-only braces **1** and gravity-loaded girders **3** in a Gravity Balance Frame. The connection can be made of steel bent-rod or steel plate with a drilled hole. In a steel structure, the connection can be bolted or welded to a girder. For a concrete structure, inserts can be

embedded into concrete girders to secure the connection, as conventionally constructed. Brace **1** can be constructed of steel cable, wire-rope, or any other commercially available materials with proven strength and stiffness. Various stiffeners may be used to ensure ductile behavior, and prevent premature failure in shear at the connection between brace **1** and girder **3**. Similarly, in a concrete structure, it shall be constructed such that ductile behavior is ensured

Figs 4a through 4c show connections between a steel column and girder as conventionally constructed, either a moment (Fig 4a), partial (Fig 4b), or simple (Fig 4c) connection, using bolts or welding.

Operation – Figs 5,6,7,8

The basic concept of the Gravity Balance Frame(GBF) is that any lateral movements of a building structure will induce an upward motion at a gravity-loaded girder due to kinematic constraints of brace **1**. The stability concept employed by the GBF is similar to a "roly-poly man" toy, as shown in Fig 5a, which is a toy that automatically stands up after being tipped over. In basic physics, a system is stable when the center of gravity is in its lowest position or has minimum potential energy. In a "roly-poly man" toy, a small lateral movement will induce an upward displacement of the toy's center of gravity, which increases the potential energy of the system. The roly-poly will return to its original position, i.e. its lowest potential energy, due to the increase in potential energy after lateral movement.

In another example often used for stability analysis, a ball resting on a concave frictionless surface represents a stable system, since it will roll back to the lowest point, i.e. lowest potential energy, after any upward displacement, as shown in Fig 5b.

Figs 6a through 6d illustrate the stability concept operating in the GBF. For clarity, Fig 6a shows a two-story building with brace **1** in an undeformed configuration, instead of the multi-

story building in Fig 1. Fig 6b shows the structure in a deformed position under a lateral load **F**, which could be due to seismic or wind load. Due to the design requirement of tension-only braces, brace **1** at the right will be stretched under tension, while brace **1** on the left side will buckle elastically under compression. The gravity load **W** on the girder will be moved upwards like the center of gravity in a "roly-poly man" toy. When the load is reversed, the action is also reversed accordingly, i.e., brace **1** on the left will be stretched in tension while the right one buckles under compression. Since the design requirement is to allow brace **1** to buckle elastically, it will resume its tension capacity and remain functional for many reversible-loading cycles. In the meanwhile, plastic hinges are formed at the middle and/or ends of girder **3**. With proper design using conventional method, the plastic hinges can also remain functional for many reversible loading cycles.

Conceptually, a pendulum and a spring can represent the GBF in an undeformed position, as shown in Fig 6c, and a deformed configuration in Fig 6d. The pendulum simulates the gravity load on the girder, while the spring simulates the stiffness of the column-and-beam frame. When the system is displaced laterally, both the pendulum and the spring will restore the system to its undeformed position, and ensure a stable and non-collapse system, as shown in Fig 6d. In technical terms, the GBF utilizes both the gravity and strain energies to balance the work by external lateral forces. A major advantage of the GBF system is that it will remain functional even after the spring yields under lateral forces, due to the presence of the gravity component. Comparatively, a conventional system utilizes only the strain energy, and therefore is not effective as a Gravity Balance Frame system.

Fig 7a shows a conventional two-story frame building in an undeformed shape, while Fig 7b shows a deformed configuration due to lateral load ***F***. Under lateral loads the right column will be in compression and move downward, while the left column will be in tension and move upward. Thus, the center of gravity of the whole structure will be balanced and not changed. However, right column **2**, being deflected laterally and under compression, tends to become

unstable once lateral deflection exceeds a certain limit. This effect is called p-delta (p-Δ) effect in a commonly used technical term.

Conceptually, the conventional system in Fig 7a can be illustrated with an inverted pendulum and a spring, as shown in Fig 7c. Once the structure is deformed, the gravity load tends to exacerbate the deformation of right column **2** in Fig 7b. The system is rendered unstable, if the deformation limit exceeded as in Fig 7d.

Fig 8a shows a conventional three-story frame system, while Fig 8b shows a corresponding GBF. Both systems are under constant gravity load **W** and gradually increased lateral load **F**. Nonlinear computer analyses are performed and the resulting load-deflection curves are shown in Fig 8c. Curve ***a*** for a convention system indicates that the structure will become unstable once the deflection exceeds a certain limit, i.e. the curve descends after peak point **A**. Curve ***b*** for a GBF system shows a much higher elastic range, which indicates that a structure will experience less damage under moderate earthquakes. Most importantly, the ascending curve after the yielding point ensures a non-collapse, stable system even after the deflection is many times over Curve ***a***.